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EFFECTS OF POLYETHYLENE GLYCOL ON THE MECHANICAL PROPERTIES OF MEDIUM CARBON LOW ALLOY STEEL

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Abstract: The effect of polyethylene glycol [H(OCH2CH2)nOH] as quenchant was studied with a view to accessing the mechanical properties and microstructural evaluation of steel. The test samples were subjected to a conventional quenching treatment process using prepared polymer solution with a definite proportion as quenching medium. The samples were characterized using a microhardness tester, universal tensile tester for the mechanical properties and a metallurgical microscope used in analyzing its structural re-orientation. From the result, it was observed that the hardness increment of the quenched samples conform to literature review as there was also a rise in the tensile properties. This though, was at the expense of their ductility. The micrographs were found to have justified the reason for the increment recorded in some of the mechanical properties, as it displayed a high proportion of the martensitic phase.
Keywords: Quenching, Polyethylene Glycol, Impact Energy

INTRODUCTION

Medium carbon steel (as-rolled) most often does not meet the requirements for some applications especially where high hardness and strength are required; this is due to their limitations in some mechanical properties. To meet these requirements, several methods of heat treatment techniques have been adopted with a view to manipulate its structure and thus widen its scope of application [6]. Among others, this technique includes the conventional normalizing process which requires the cooling of the materials in natural air to enhance the relief of stress that might have been induced during the manufacturing process; annealing, as it involves the cooling of the material in the furnace after heating to a predetermined austenitic temperature. Other conventional techniques are quenching and tempering operations [4].

Quenching is another heat treatment operation which has been adopted for decades now to introduce and improve high hardness and strength properties on steel [3]. In most cases however, it is observed to be at the expense of its ductility [5]. This operation involves the heating of the material to austenitic state and allowed to cool rapidly (Quenching) in a defined cooling medium such that the atoms will be forced to undergo a re-orientation and then results to the desired properties.

Several media are being used in the cooling of steel during quenching operations. The selection of cooling medium depends, to a large extent, on the desired properties and application. Some of the media that have been conventionally used includes water, brine and oil. Recently however, the use of polymer has begun to gain relevance in the quenching operation.

Some researchers have been working tirelessly investigating the effect of polymer quenchants on the properties of steel [1,2]. All of these researchers have narrowed their study to low carbon steel with a view to improve the strength and justify it with the developed structures. Some of these researchers, who despite their intense efforts, have not studied and analyzed its effect on medium carbon steel when subjected to quenching operations in polymer, and the need to do that serves as a reason for this project.

MATERIALS AND METHOD

Materials and Equipment

With the aim of determining the response of steel to polymer (Polyethylene glycol) quenching operation, a commercially available carbon steel of chemical composition shown in Table 1 was procured. Polyethylene glycol – $H(OCH_2CH_2)_nOH$ [where n represent the average number of oxyethylene groups] – was also procured to serve as the quenchant. The equipment used to carry out the experiment includes: muffle furnace, hack saw, bench vice, spectrometer, instron universal tensile testing machine, microhardness testing machine, and metallurgical microscope.

Table 1: Chemical composition of the steel used in this experiment

Elements	C	Si	S	P
Composition	0.3800	0.1630	0.0399	0.0301
Elements	Mn	Ni	Mo	V
Composition	0.7425	0.0911	0.00180	0.0029
Elements	Cu	W	Cr	Co
Composition	0.3031	0.0003	0.0555	0.0094
Elements	Al	Ca	Zn	As
Composition	0.0019	0.0002	0.0037	0.0060
Elements	Sn	Fe		
Composition	0.0230	98.1858		

Method

The as-received 12mm diameter rod was firstly taken to U-Steel Ltd, Lagos for spectrometric analysis where it was confirmed to contain 0.38% carbon content. The bulk rod was machined to tensile and impact configurations using medium size lathe machine while pieces were also cut for microhardness evaluation. Four sample sets were machined each for the pre determined three different PEG mixture proportion and for the control. The samples were initially normalized so as to annul the mechanical history of the machined specimen and this serves as the initial microstructure for the experiment. Subsequently, all samples were heat treated to austenitic region in a muffle furnace and held for 60 minutes respectively prior to rapid cooling in prepared polymer mixtures of 20, 40 and 60% of Polyethylene glycol (PEG). The treated samples were designated to avoid mix-up in the course of characterization (See Table 2). The resulting developed structure were characterized and analyzed.

Table 2: Sample's designation

Label	Polymer : H_2O
Sample A	Normalized
Sample B	3:7
Sample C	2:8
Sample D	1:9

RESULTS AND DISCUSSION

» Effects of polymer quenching on the microhardness of medium carbon steel

Figure 1 shows the hardness plots of the steel and its improvement after quenching operation was carried out. The untreated sample (Sample A) was observed to have the least hardness value thus indicating its unreliability in certain applications where high hardness is required. The effects of the quenching operation were explicit in other sample as they all exhibited higher hardness values. Sample C which was quenched in 2:8 polymer: water mixture respectively was observed to exhibit the highest hardness value of 431.7HV in comparison to the control sample that possess 238.9HV thus translating into 80.7% increment. The reason for this expected increment could be attributed to the very short time expended in bringing the temperature of the heated sample to a lower temperature such that no reaction would occur within the atoms of the material during the quenching process. This will be further discussed in the course of this section.

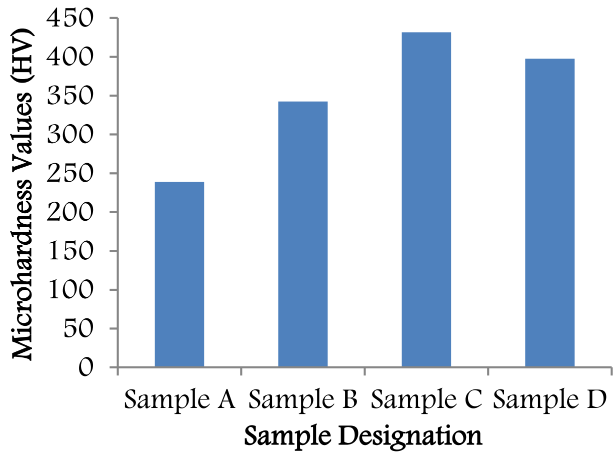

Figure 1: Variation of Hardness to Quenchant proportion

» Effects of polymer quenching on the impact energy of medium carbon steel

A progression in the impact strength with respect to the quenching media proportion was observed in the result (See Figure 2). The control sample as conventionally expected, displayed the least strength, while the quenched sample displayed interesting values that indicate that the proportion of the mixture for quenching is a factor in determining the impact strength of steel. Sample D quenched in 1:9 polymer:water exhibited the highest value indicating that it has the highest tendency to withstand sudden shock at a predefined condition prior to failure.

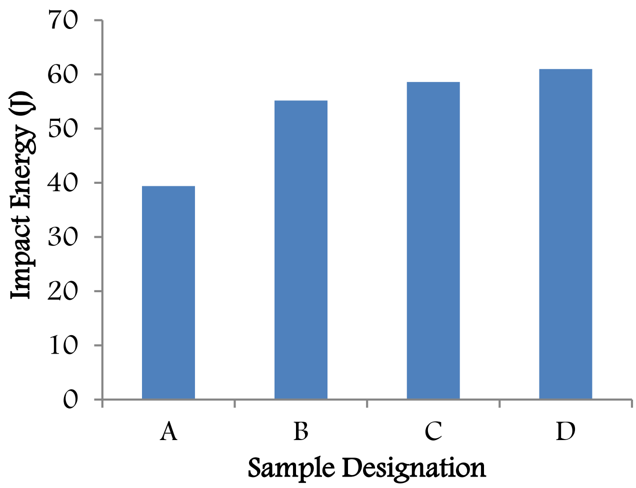

Figure 2: Variation of impact strength to quenching media ratio

» Effects of polymer quenching on the tensile properties of medium carbon steel

Figure 3 and 4 are the plots showing the tensile properties of the quenched and unquenched steel. The result of the ultimate tensile strength (UTS) for the unquenched steel corresponds to findings in literature review [3,5].

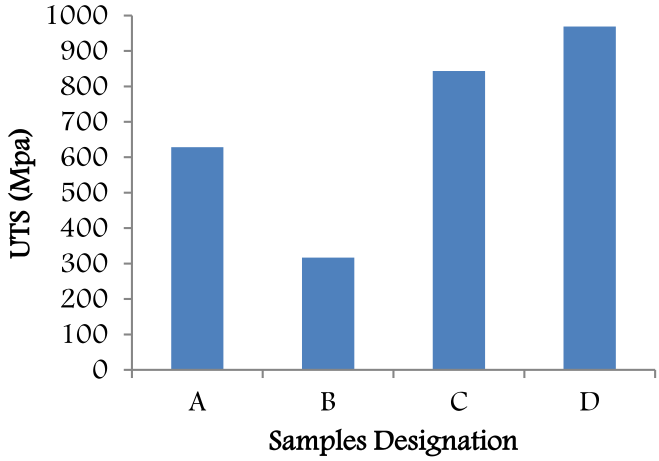

Figure 3: Plot of ultimate tensile strength versus the designation

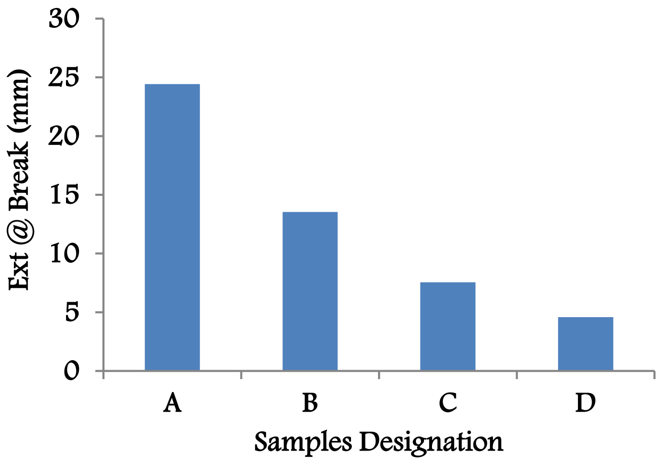

Figure 4: plot of extension of the steel at break versus the sample designation

While samples C and D were observed to display high UTS values (See Figure 4.3), Sample B however showed a reduction in comparison to the control sample. The reason for this could be attributed to an emergence of crack on the sample during quenching operation. Summarily, Sample D quenched in 1:9 mixture of Polymer and water respectively displayed the highest value for UTS indicating its ability to withstand higher load than others. This however, is a risk not worth taking as its ductility had drastically reduced as depicted by the results in Figure 4. Here, all quenched sample were observed to have sacrificed their ductility for strength and hardness as the unquenched possess the highest extension prior to failure thus indicating its high endurance limit at fixed load. The least 'extension at break' value displayed by Sample D showed that it is brittle and its failure will be catastrophic as there will be little or no notification prior to fracture.

» **Effects of polymer quenching on the microstructure of medium carbon steel**

The microstructures obtained are shown in the Plate 1 – 4.

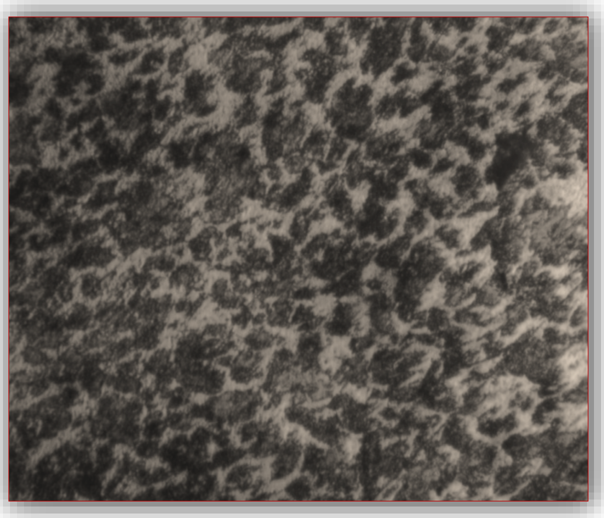

Plate 1: Microstructure of sample A (control – after normalizing operation) – 200X

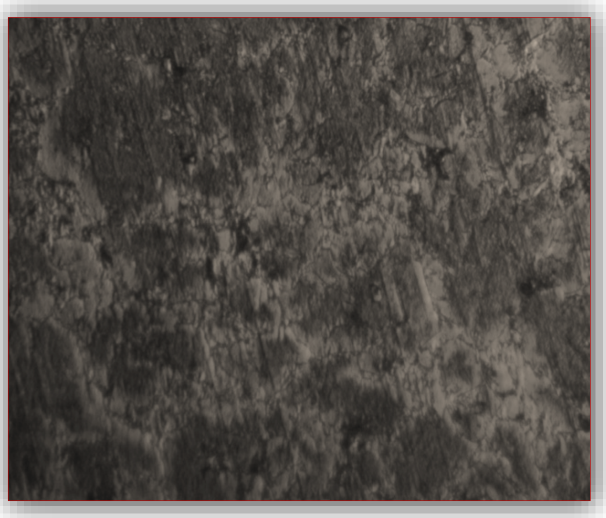

Plate 2: Microstructure of sample B 60 percent by volume of PEG (after quenching operation) – 200X

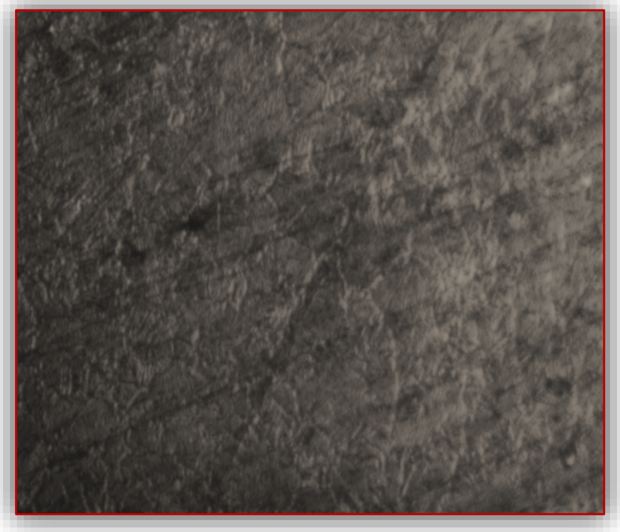

Plate 3: Microstructure of sample C 40 percent by volume of PEG (after quenching operation) – 200X

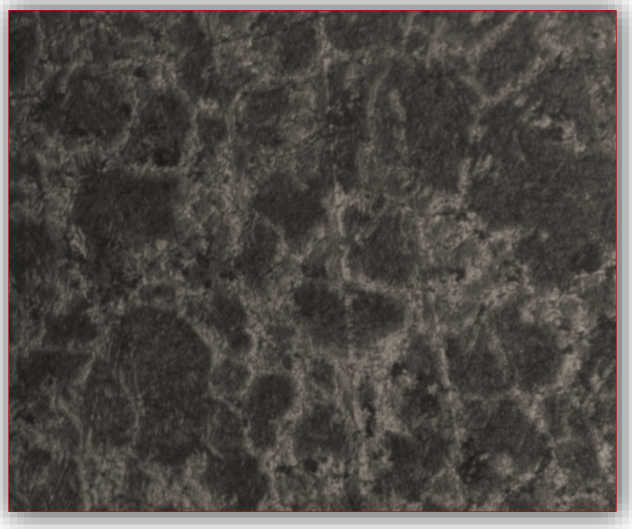

Plate 4: Microstructure of sample D 20 percent by volume of PEG (after quenching operation) - 200X

The microstructure produced by the control sample consists of pearlitic-ferritic structure while the microstructures produced by the processes consist of a finely distributed ferrite-martensite microstructure. The strong deformable second phase consists predominantly martensite with some retained austenite. Martensite provides the strength in the steel which justifies the improvement in some of the mechanical properties as earlier discussed; whereas the ferrite provides the ductility. The strong second phase is dispersed in a soft ductile ferrite matrix.

CONCLUSION

The effect of $H(OCH_2CH_2)_nOH$ (polyethylene glycol) as quenchant was studied with a view to access the mechanical properties and microstructural evaluation of medium carbon steel. The test samples were subjected to a conventional quenching treatment process, and quenched in a prepared polymer solution with a definite proportion. The samples were characterized using a microhardness tester and universal tensile tester for the mechanical properties and metallurgical microscope used in analyzing its structural re-orientation. From the results, it was observed that the hardness increment of the quenched samples conform to literature review as there was also a rise in the tensile properties. This though, was at the expense of their ductility. The micrographs was found to have justified the reason for the increment recorded in some of the mechanical properties as it displayed high proportion of martensitic phase.

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